Unlocking Urban Animal Response to Reduced Human Activity during COVID-19 Lockdown

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Abstract

The interrelations between human activity and animal populations are of increasing interest due to the emergence of the novel COVID-19 across the world. Anthropogenic impacts of the pandemic on animals in urban-suburban environments, at this stage, are largely unknown. In this study, temporal and spatial aspects of urban animal response to the COVID-19 lockdown were assessed using animal-vehicle collisions (AVC) data. We used AVC and traffic data over two six-month periods in 2019 and 2020 (January to June) from southern Poland, which included lockdown months. Our analysis of 1741 AVC incidents involving 21 animal species revealed that COVID-19 related lockdown did not significantly impact AVC rates even though traffic levels were reduced, suggesting that animals increased utilisation of urban-suburban interfaces in response to reduced human activity. Given the high incidence and diversity of species involved in AVC in this study, we emphasise the importance of data integrity and mitigation measures to minimise this human wildlife conflict.

Introduction

Humans and wildlife have co-existed in urban environments for as long as human settlements have occurred [1]. Ever-expanding human populations are transforming environments at unprecedented rates, therefore, understanding the linkages between human and animal interactions are of critical importance given that human activities affect animal distribution, behaviour and movement [2,3]. Declared a global pandemic in March 2020, the outbreak of the novel coronavirus known as SARS-CoV-2 (COVID-19) in early 2020 has brought about major changes to human dynamics on a global scale [4]. Governments have restricted people's mobility through multilevel lockdowns of educational institutions, workplaces, and international travel to prevent the spread of disease.

The pandemic and resultant reduction in human activity have also had considerable localised consequences for animals. For example, on a positive note, there has been a reduction in stress on sensitive animal species in protected areas (Corlett et al., 2020), increases in the level of illegal hunting due to the reduction of enforcement and protection measures [5,6] and reports of other species venturing into urban settings including pumas (*Felis concolor*) [7], dolphins (*Delphinus* spp.) and golden jackals (*Canis aureus*) [8]. Globally, researchers are advocating for further research to understand the positive and negative effects resulting from COVID-related-human lockdown and its consequent relaxation (i.e., the Global Human Confinement Experiment [9]).

Scientists have long sought to quantify how human activities can affect various aspects of wildlife ecology including movement and animal activity [8]. Studying the movement of animals in urban landscapes during a lockdown provides a unique opportunity to investigate one of the main drivers of this process [10,11]. An important data source on animal movement and activity is animal-vehicle collisions (AVC) being not only of conservation concern, but also a key human-wildlife conflict and a threat to human safety [12,13]. There has been a growing number of cases of AVC worldwide due to increases in road networks and consequent increases in traffic level [14], which are more intensified in urban environments. Around 194 million birds and

29 million mammals are killed annually on European roads [15] with ungulates alone exceeding 1 million per year [16]. In a recent study by Bíl [15] it was found that wildlife vehicle collisions (WVC) had mostly reduced in many countries (e.g., in Spain, Estonia or Czech Republic) during the COVID-19 lockdown period however with varying rates. This board study across Europe showed that each country responded differently to reduced human mobility due to lockdown nationwide. Therefore, we wanted to explore if lockdown affected similarly both in urban and suburban areas in the background of the dynamics of human mobility.

Thus, the aim of this study was to identify any effects of changes in human and vehicular activity on AVC in an urban-suburban landscape during the COVID-19 pandemic in Poland. We used AVC data over two six-month periods collected in the Krakow metropolitan area of Poland (which included urban commune of Krakow, and suburban communes of Wieliczka and Niepolomice). In our analyses, the lockdown period in 2020 was defined from March to May, hereafter termed 'lockdown' months based on the official government declaration [17]. The months from January to June 2019 and, January, February and June 2020 were termed as 'non-lockdown' months. Both 2019 and 2020 were similar in terms of meteorological conditions in winter (January to March) and spring months (April to June) and there were also no essential landcover or human populations changes between these periods, controlling for any potential effects of such variables on analytical outcomes. The three main research questions in our study were to investigate whether (1) reduced human mobility due to lockdown caused changes in the incidence of AVC between the urban and suburban areas; (2) AVC was influenced by working hours for essential services even during the lockdown; and (3) AVC within the urban area decreased with the traffic volume during the lockdown. Through this study, we explore the impact of changes induced by COVID-19 and reduced traffic volume (understood as number of vehicles per hour) on AVC dynamics within an urban-suburban environment between 2019 and 2020.

Results

A total of 1741 AVC incidents involving 21 animal species were reported during the study period. The detailed descriptive statistics is provided in Table 1. Wild boar (*Sus scrofa*), red fox (*Vulpes vulpes*), domestic dog (*Canis lupus familiaris*) and cat (*Felis catus*), roe deer (*Capreolus capreolus*), brown hare (*Lepus europaeus*) and bird species were the most common animals involved in road collisions in all three locations of Krakow, Wieliczka and Niepolomice.

Table 1
The total and mean (±SD) animal-vehicle collision (AVC) number during non-lockdown (January, February and June) and lockdown periods (March, April and May) recorded in the study area. SD- Standard deviation

Commune	Year	Period*	Total AVC	Mean AVC (per month)	SD
Krakow	2019	Non lockdown months	267	89.00	38.94
		Lockdown months	390	130.00	9.17
	2020	Non lockdown months	276	92.00	9.64
		Lockdown months	380	126.67	9.50
Niepolomice	2019	Non lockdown months	43	14.33	4.51
		Lockdown months	54	18.00	2.65
	2020	Non lockdown months	47	15.67	3.21
		Lockdown months	35	11.67	4.51
Wieliczka	2019	Non lockdown months	73	24.33	6.35
		Lockdown months	86	28.67	7.51
	2020	Non lockdown months	67	22.33	4.16
		Lockdown months	68	22.67	9.61

Effect of urbanisation on AVC.

Multidimensional Scaling or MDS was performed with Jaccard index to measure the variation in the dataset. The overall variation in AVC was distinct across the urban and suburban communes (Fig. 1a). Canonical Correlation Analysis (CCA) showed that the location factor explained 13.45% of the variance in the dataset (n=36), separating urban commune of Krakow from suburban communes of Niepolomice and Wieliczka. The pairwise PERMANOVA showed a significant difference ($p \le 0.05$) of variation in AVC between urban and suburban communes, but not significant between suburban communes (Fig. 1a; S2a). We found an overall decrease of AVC between 2019 and 2020 in suburban communes, but the AVC rates were almost similar in Krakow between 2019 and 2020 (Fig. 1b). Upon pairwise comparative analysis of AVC among locations, AVC for wild boar, red fox, dog, domestic cat (*Felis catus*), birds, roe deer, hedgehog (*Erinaceus roumanicus*), rats (*Rattus* spp.), brown hare, squirrel (*Sciurus vulgaris*) and Eurasian badger (*Meles meles*) were significantly higher in Krakow than in Niepolomice and Wieliczka (Fig. 1c). However, there was no significant mean difference in AVC for any of the species among the suburban communes (Fig. 1c). The analysis of difference in AVC between lockdown and non-lockdown months showed no statistical significance (FDR>0.05) (Fig. 1d).

Working hours and its impact on AVC.

The most common animals involved in collisions during lockdown across all the time range were red fox, dog, wild boar, domestic cat, hedgehog and birds (Fig. 2a). This showed high incidences of AVC in Krakow than in Wieliczka and Niepolomice. The MDS showed 26.43% of variations on constraining factors such as location, lockdown and time (n=188) (Fig S2a). Our analysis revealed a significant effect (FDR$\leq$ 0.05) of location and time on AVC (Fig. S2b), however, lockdown did not bring any significant variation (Fig. S2a-c). This indicated that the reduced human mobility due to lockdown did not impact the AVC in the studied regions, but location (Krakow, Niepolomice and Wieliczka) and time did influence AVC.

The AVC for each species for the three regions and across 24 hour is shown in the heat map (Fig. 3a). AVC in Krakow did not show any time related difference between non-lockdown and lockdown periods although there were significant differences for certain species in the suburban communes of Wieliczka and Niepolomice (Fig. 3b). These species were red fox, dog, wild boar, domestic cat, birds and hedgehog, which encountered less AVC during the lockdown period. For example, in Niepolomice, AVC incidents involving red fox were recorded within a 4-hour period (12:00-16:00h) during lockdown, as compared to a 12-hour period (04:00-16:00h) during non-lockdown (Fig. 3a). A similar pattern was found for red foxes in Wieliczka (Fig. 3a). Considering wild boar AVC in Niepolomice and Wieliczka, similar results were found in terms of a significant reduction of AVC incidents in suburban communes during lockdown (Fig. 3a).

Analysing the trend of variation in total AVC along the time range in different locations (as shown by LOESS fitted line plot, Fig. 3c) indicated that total AVC were generally higher in Krakow than in suburban areas, and that AVC in Krakow had the peak in the early working hours. AVC in Krakow had the peak in the early working hours (6am to 10am) during lockdown while the peak comes later in the suburban areas.

Traffic in Krakow and its impact on AVC.

The mean (±SD) number of vehicles per hour between January to June in 2019 was 24116 (±11827.78), while in the same period in 2020 it was 20891 (±5839.99). Traffic volume in Krakow decreased significantly during the lockdown months with April having the highest mean difference in traffic volume. However, despite significantly lower traffic, total AVC in Krakow did not decrease significantly, during the lockdown (Fig. 4a), in Krakow. The only exception was for weasel (*Mustela nivalis*) and jackal (*Canis aureus*) which showed significant reduction in AVC in 2020 during non-lockdown and lockdown months respectively. The Spearman's correlation analysis (r_s= -0.51; p=0.01) between mean difference in traffic volume and mean difference in AVC showed reduction of traffic volume in Krakow did not reduce AVC in the city (Fig. 4b). Additionally, integration of the components from MDS analysis showed the effect of lockdown in the reduction in traffic volume but not in the decrease of AVC (Fig. S3).

Spatial patterns change of AVC.

The spatial pattern of AVC analysed independently for pre-lockdown months (January-February), lockdown months (March-May) and for June differed substantially. Comparison of the pre-lockdown months showed higher number of incidents located in the proximity of forest habitats, in the western and eastern part of the study area in 2020 in comparison to 2019 (Fig. 5). Comparison of March-May periods indicated although lower, yet not a huge disparity in AVC in 2020 throughout the study area with very minor exceptions in suburban areas in the south. AVC changes in June, by contrast, showed increase in incidents in 2020 as compared to 2019 in the southern and northern part of the study area, while eastern part experienced slight decrease in the incidents (Fig. 5).

Discussion

In our study we examined three main questions to address the effect of reduced human and vehicular activity on AVC during COVID-19 lockdown. Firstly, we examined whether reduced human mobility due to lockdown would cause changes in the incidence of AVC between urban and suburban areas. Secondly, we enquired if AVC would be influenced by working hours for essential services during the lockdown and finally, whether AVC in the urban area (city) would decrease with the traffic volume. To the best of our knowledge this is one of the early studies analysing the impacts of COVID 19 induced lockdown on wildlife in Poland.

In relation to the first question, we found that only urban commune of Krakow was associated with the highest frequency of AVC irrespective of the studied period (lockdown vs non lockdown). In suburban communes of Niepolomice and Wieliczka communes, the AVC incidents were in general less frequent than in Krakow, and significantly lower in lockdown period. This could be explained by the fact a smaller number of people commuting to work in Krakow from surrounding suburbs during lockdown. Increased numbers of AVC with greater traffic (as in urban areas) is intuitive and has been found in numerous studies [14,23,24]. Although the obvious potential implication of lockdown would correspond to lower AVC, our results indicated that in the urban area, the pattern of AVC during lockdown, whilst lower, was not significantly different from non-lockdown periods even when there was less traffic during lockdown. In particular, our results showed that certain animals (for e.g., wild boar, red fox, domestic dog and cat, birds, roe deer, hedgehog, hare, squirrel and badger) were involved in collisions more in the urban area in comparison to the suburban areas irrespective of lockdown. This may be attributed to animals foraging in the city, exploiting the sudden human absence caused by lockdown procedures [25]. Krakow city can be especially prone to increased animal activity when human impacts are reduced, due to several migration corridors of regional or European (Vistula River) importance, and favourable land cover (i.e., western wedge of greenery) [26]. Similarly, in the study by Bíl [15] it was found that WVC did not decrease in all studied regions during COVID-19 related travel restrictions (for e.g., in Scotland). However, it is also necessary to mention that our scale of analysis was different which could be a potential factor in reduced AVC in our studied area, as most often nation-wide studies may not indicate internal variations.

Our second question revealed that AVC was more pronounced during the early morning hours in Krakow which is consistent with other studies [27,28], however this pattern was also observed during the lockdown. The most common conflictual wild animals in Krakow have been identified as wild boar, roe deer and medium sized carnivores such as red fox in all three study areas. Roe deer did not show any significant difference in AVC in all three study sites between lockdown and non-lockdown over the 24h period. In suburban areas, wild boar and red fox were involved in AVC for a shorter time span during lockdown compared to non-lockdown period. This can be explained by the fact that red foxes [29] and wild boars [30] have shown to exhibit behavioural plasticity in activity patterns in its native range, which allows it to adapt to environmental changes. On the contrary, road crossings by roe deer are mainly driven by their behavioural patterns rather than directly by the volume of traffic on a road [31]. Additionally, the frequency of AVC for red foxes and wild boars decreased in lockdown period (Fig. 3b). Again, this can be attributed to higher traffic volume during non-lockdown period over 24h compared to certain time peaks of traffic during lockdown.

Finally, we found no significant differences in total AVC between lockdown and non-lockdown periods in Krakow, even though there was a significant reduction in traffic volume during lockdown months. The relationship between traffic volume and the number of AVC has led to divergent conclusions being presented in studies published to-date. For example, some studies showed positive relationship between traffic volume and AVC, [32,33] indicating high road kills during high traffic whereas few studies did not find any strong effects [34–36]. Thus, there may not always be a linear relationship between traffic volume and AVC [37]. Our study showed a negative correlation between traffic volume during lockdown and AVC in the city indicating higher number of AVC irrespective of reduced traffic volume. We therefore suggest that animals within the study area responded to lockdown by increasing their activity and movement within urban environments, which resulted in relative comparable levels of AVC despite the decrease in traffic volume. This may seem counter intuitive as reduced traffic levels may have been expected to have resulted in reduced levels of AVC. However, Seiler and Helldin [38] have argued that low traffic volume coupled with greater speed of vehicles leads to the highest animal mortality rates. This is due to the longer time interval between subsequent rapidly approaching vehicles, that stimulates an animal to attempt to cross the road thereby increasing the likelihood of collision [39]. In other words, intermediate traffic volumes may result in higher rates of collisions than large traffic volumes because animals may be more willing to attempt to cross roads and highways with moderate than high traffic volume [37].

However, our results do not rule out the existence of other factors influencing AVC, although, establishing reliable AVC patterns in any study area can be difficult. Furthermore, AVC datasets can be subject to errors, biases or underrepresentation in case of minor damage. One of the major drawbacks of our study was the small number of AVC of certain species which could have affected the results. There are also spatial (e.g., part of one country) and temporal (e.g., confined to two years) limitations. Additionally, there were no data on traffic volume for Wieliczka and Niepolomice during the study period. Nevertheless, it should be acknowledged here that the collected and analysed data in this study were based on police or authorised reports. Although such reports are not without sampling errors, these are the best reliable and available data source to analyse AVC. Simultaneously, it should be recognised that AVC data allow us to identify at a coarse-scale the location (hot spots) of higher occurrence of conflicts with animals. Being a non-invasive method, AVC data allows to gather records for a wide range of species at the same time, which sometimes is comparatively difficult to achieve with other monitoring methods.

Conclusion

Our findings reveal that high frequency of AVC existed in the urban area even during the lockdown and reduced traffic volume in the city did not correspond to reduction of AVC. Considering these findings within the context of reduced human activity during COVID-19 restrictions, our results argued that the global pandemic has had a limited impact on AVC levels within the urban study area. We understand that the AVC levels were quite high, especially in the urban commune and possibly this problem is only to some point addressed in the current mitigation measures. Thus, we emphasise on the importance of developing targeted mitigation strategies, high quality data and reporting systems [37] including the use of AVC hotspot mapping, reduced speed limits, speed bumps and warning road signage in key areas to reduce AVC as a source of human wildlife conflict [40]. The construction of animal underpasses beneath expressways is often implemented especially in southern Poland [41,42] but such approaches are unfeasible in established urban environments.

Although there is no denying that society's immediate and ongoing priority at this hour should be containing the pandemic, but the crisis provides an opportunity to be cognizant of the importance between healthy, resilient ecosystems and human well-being [43]. Identifying the cause of the risk factors (human, traffic, road) influencing vehicle collisions with animals is essential to develop prevention strategies [44] that will decrease mortality and impending conflicts. By providing an analysis of AVC data in urban-suburban areas during COVID-19 lockdown, our findings give an insight into the presence of wild animals and impending conflicts in these specific landscapes.

Methods

Study area.

The study was conducted in southern Poland within the Krakow metropolitan area, and comprises three communes of Krakow, Wieliczka, and Niepolomice, representing various levels of urbanisation (Fig. 6, Table 2). The urban commune of Krakow encompasses an area of 327 km^2 and has a human population of 779,115 (DSIPM 2020). It is an important transportation hub for major national and international roads, and is bisected by the Vistula River, a natural migration corridor for many wildlife species (Baścik and Degórska 2015). In terms of Krakow's landcover, built-up and urbanised areas constitute over 45% of the city, with 44% of the city used for agricultural purposes including crops, orchards, meadows and pastures.

Table 2
Main descriptors of the study areas

Commune	Level of urbanisation	Total area (km^2)	Total population	Population density (person/km^2)	Agricultural land (%)	Forested land (%)	Built-up area (%)
Krakow	Urban	326.9	779115	2383	43.8	1.7	46.9
Wieliczka	Suburban	99.7	60781	610	73	7.8	19
Niepolomice	Suburban	96.3	29141	303	67	15	17

Wieliczka and Niepolomice are mainly agricultural and forested suburban communes neighbouring Krakow (Fig. 6), each covering an area of approximately 100 km^2, with a population of 60,781 and 29,141 citizens, respectively. In terms of land cover, built-up and urbanised areas constitute approximately 20% and agricultural land constitutes almost 70% in both suburban communes (Table 2).

Wild animals are common in the study area. In urban parks and in forest patches at the outskirts of the Krakow city, red fox, roe deer and wild boar can be found. The common wild animals found in Wieliczka are red deer (*Cervus elaphus*), roe deer, red fox and Eurasian badger. Niepolomice commune, on the other hand, encompasses the large Niepolomice forest, a special protection area and Natura 2000 site, inhabited by large wild ungulates including moose (*Alces alces*), red deer, roe deer and wild boar. For this reason, we primarily focused on effect of lockdown on AVC of mammals and have grouped all birds together.

Data collection and processing.

AVC data were collected daily in 2019 and 2020 by KABAN Company under contract from a range of local authorities. KABAN Co., working for Krakow Municipality and the Regional Directorate of Nature Protection in Krakow, was obliged to manage each AVC incident (from birds to large mammals) reported by municipal institutions, such as Police, City Guard Service, District Centre of Crisis Management and Krakow Animal Shelter. All of these institutions have emergency phone numbers that operates 24 hours, 7 days a week, and any AVC incident must legally be reported immediately, especially in the densely inhabited areas. KABAN Co. officers received phone calls from these institutions about AVC and verified each reported incident by visiting the locations followed by undertaking appropriate procedure e.g., translocating the wounded animal to animal shelter. The reporting time between an AVC incident and the phone calls to KABAN Co is approximately 30 minutes (Maciej Lesiak personal information). The details of each AVC including date and location of incident, animal species, incident characteristics and time of reporting were recorded in a database (Table S1).

The exact point addresses were available only for 48% of the AVC, thus, we analysed the locations of AVC in relation to street names, which were provided in all reports. Street network data were obtained from OpenStreetMap (accessed on 29.11.2020), with main streets defined as those of primary, secondary and tertiary road type. We have further divided the study area into smaller regions (n=533), where each region contains a main street with smaller streets connected to it and their neighbouring areas (defined using closest Euclidean proximity rule), which allowed to investigate the change in spatial pattern of AVC. AVC were summarised within these regions with regard to year (2019 and 2020) and month (January-February, March-May, and June).

Traffic volume data (i.e., number of vehicles per hour) were available only from Krakow and were obtained from the Department of City Traffic through the light detection system installed at major roads for the city of Krakow. The detection system counts the number of vehicles crossing the road at 19 major roads in the city and collected data for the entire period on an hourly basis (Table S2). The traffic volume data for Krakow can be, however, use as a proxy to reflect the traffic situation not only within the city itself, but also in the whole agglomeration, as large part of the within-city traffic on major roads is connected with commuters traveling from suburban areas to the city.

Statistical Analysis.

AVC data were analysed using unconstrained (Multidimensional Scaling or, MDS) and constrained (Canonical Correlation Analysis or, CCA) ordination methods. Ordination methods are used in multivariate data for determining differences between samples in a graphical manner. Unconstrained ordination is useful for viewing overall variation in the data (i.e., to represent, the pairwise dissimilarity between objects), whereas constrained ordinations reveal variation of a fixed factor(s) by minimising the effect size of the random factors [18]. All data analyses were performed in the R environment [19], using tidyverse [20], Vegan [21] and RVAideMemoire [22] packages. All packages and dependencies were encapsulated in anaconda environment at https://github.com/SAYANTANI26/ProjectAVC/. The detailed data stratification and workflow has been shown in Fig. 7.

Analysis for influence of AVC in urban and suburban areas.

To assess the impact of lockdown associated with COVID-19 on AVC, the AVC data were stratified by location (understood as commune, i.e., Krakow, Wieliczka and Niepolomice), month (January, February, March, April, May, and June), and year (2019 and 2020) (see for data stratification Fig. 7). The stratified data was normalised and scaled to 1 for all further analysis. The MDS analysis was performed by computing pairwise Jaccard index (Hancock 2014) as a distance measure. The dataset was further estimated by CCA using location as constrained variable and conditioned by year. Statistical significance ($p \leq 0.05$) of locations was determined by performing PERMANOVA and the variation within location by pairwise PERMANOVA (over 1,000 permutations). The *p*-value for pairwise analysis was adjusted using the Benjamini–Hochberg (BH) procedure. Next, we represented AVC patterns for each species (mammals and birds) using heat maps for visual inspection. Heat maps generally help to visualise the intensity (high or low) of AVC for each species in three locations. Finally, by generalised linear model (GLM) we analysed the mean difference of AVC between locations and lockdown (fixed factors). The statistical significance was computed by conducting Tukey's Honest Significance Difference (HSD) test and the *p*-value was adjusted using the BH procedure. Animal species that showed a mean difference with false discovery rate (FDR) $\leq$ 0.05 were considered to be significant and the percentage of AVC for those animals were represented in the boxplots.

Analysis for AVC during working hours.

To assess the impact of AVC during working hours, the AVC data was grouped by summing the AVC reports for each day and each month within the 24-hour (h) time period of the corresponding location (commune). The time period was split into six intervals of 4h time periods (00:00 - 04:00h, 04:00 - 08:00h, 08:00 - 12:00h, 12:00 - 16:00h, 16:00 - 20:00h and 20:00 - 00:00h). Additionally, we estimated the total AVC across time by stratifying month, year and location (see for data stratification Fig. 7). The dataset was then treated similarly as in 2.3.1, i.e., normalised to 1, and presented using heat maps for visual inspection. The normalised data was subjected to MDS (with Jaccard index) and CCA analysis with the lockdown and location as constrained factors and day, month and year as random factors. The statistical significance was reported by conducting PERMANOVA on CCA over 1000 iterations. By GLM we analysed the mean difference in AVC reported for specific animals between locations during the lockdown period. The trend of variation in total AVC along the time range was represented by fitting the total AVC by locally estimated scatterplot smoothing (LOESS) method and MDS analysis for respective time period.

Analysis for AVC and traffic volume in the urban area.

Finally, to assess the influence of traffic volume (i.e., number of vehicles per hour) on AVC during the lockdown, the traffic and the AVC dataset (stratified by month and 24h time period) for Krakow was integrated to analyse the association of vehicle movement and its impact on AVC. The traffic volume data was normalised by dividing the number of vehicles (per hour) by 1 000 000 (in million) to ease calculation. We independently compared the datasets for each parameter (animal species, total AVC and traffic volume) within Krakow between the exact months of 2019 and 2020 (fixed factor) and lockdown. By GLM, we analysed the effect of lockdown and year for each parameter and the statistical significance was reported (same as in 3.2.1). The relationship between the traffic volume (converted to per million within 24h time period) and AVC was determined by conducting Spearman's rank correlation (rho) on the respective mean difference and also by combining component 1 and 2 of their MDS analysis.

Declarations

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Author contributions

S.M.B and I.A.W conceived the idea; M.L. collected the data; S.M.B and A.K.B analysed the data; E.Z and D.K analysed spatial data; D.T.M., S.M.B, A.K.B, E.Z., D.K. and M.S.S led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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Competing interests

The authors declare no competing interests.

Data Accessibility

Datasets of all spectra shown are available in: R scripts used to generate figures are available at: https://github.com/SAYANTANI26/ProjectAVC

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Figures

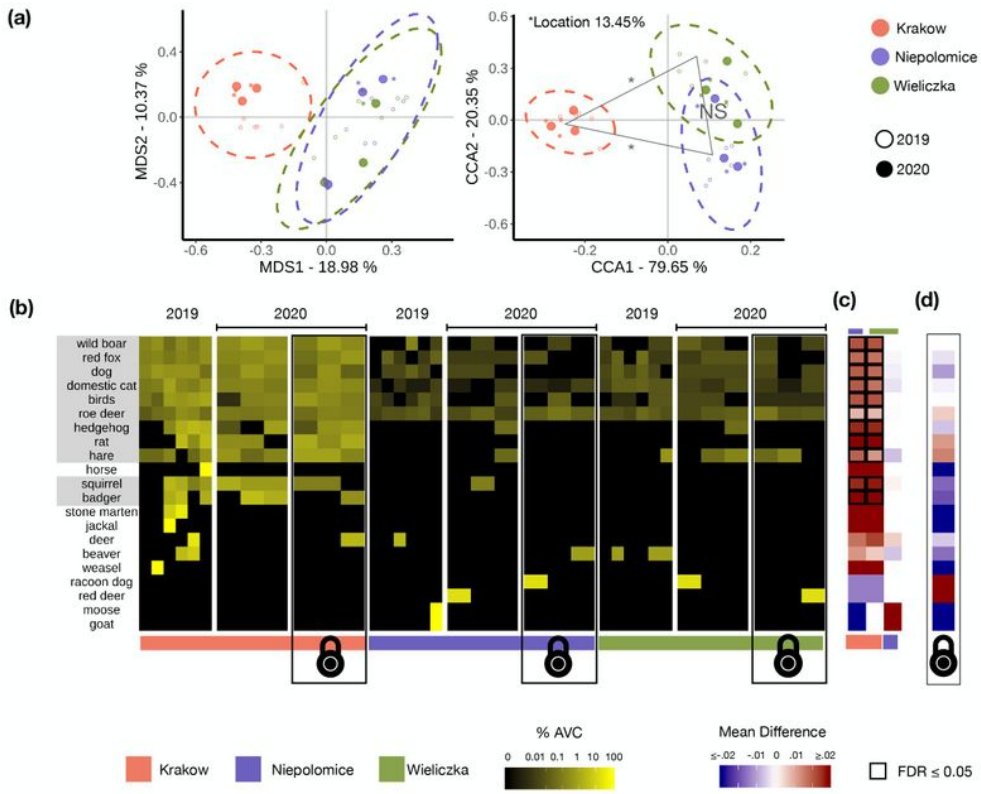

Figure 1

Effect of urbanisation and lockdown on AVC (a) Unconstrained ordination shows Multidimensional scaling analysis (MDS) plot (left) displaying the variance explained in component 1 and 2. The dots represent data stratified by month (with lockdown months distinguished by larger dots). Colours of dots represent the location, and unfilled dots stand for 2019 and filled for 2020. Constrained ordination (right) showed the variance by location as the constraining factor and year as random factor. NS= Not significant; * = p ≤0.05 represents significance between locations determined by pairwise PERMANOVA. The ellipses represent 95%

of the confidence interval; (b) The heatmap displaying the percentage of AVC (intensity of colour black to yellow) for the animals reported (y-axis) over a period of month (x-axis) across year for specific location. The lockdown month is facetted out in the year 2020 for the corresponding locations. The grey boxes on the names of animals indicate the animals that significantly differed between the locations; (c) The pairwise comparative statistics performed on location as fixed factors. The colour bars represent the different locations showing the explanatory variable (bottom) and the comparator (top); (d) Pairwise statistics performed to show the significant mean difference between lockdown and non-lockdown.

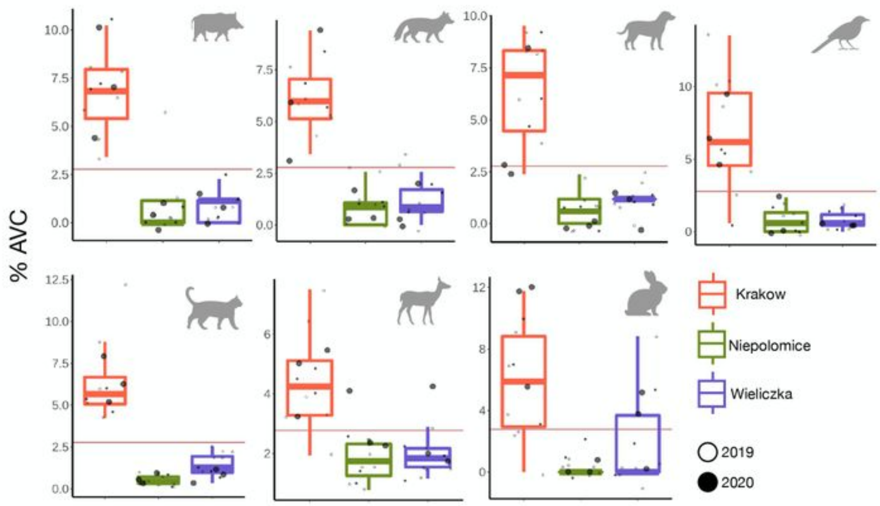

Figure 2

Comparison of the distribution of reported percentage of AVC (y-axis) of the corresponding locations over the years (shape fill) for the animals. The boxes represent the 25th, 50th (median) and 75th percentiles of the data; the whiskers represent the lowest (or highest) datum within 1.5× interquartile range from the 25th (or 75th) percentile. The horizontal red line indicates the overall mean % of AVC of the specific animal.

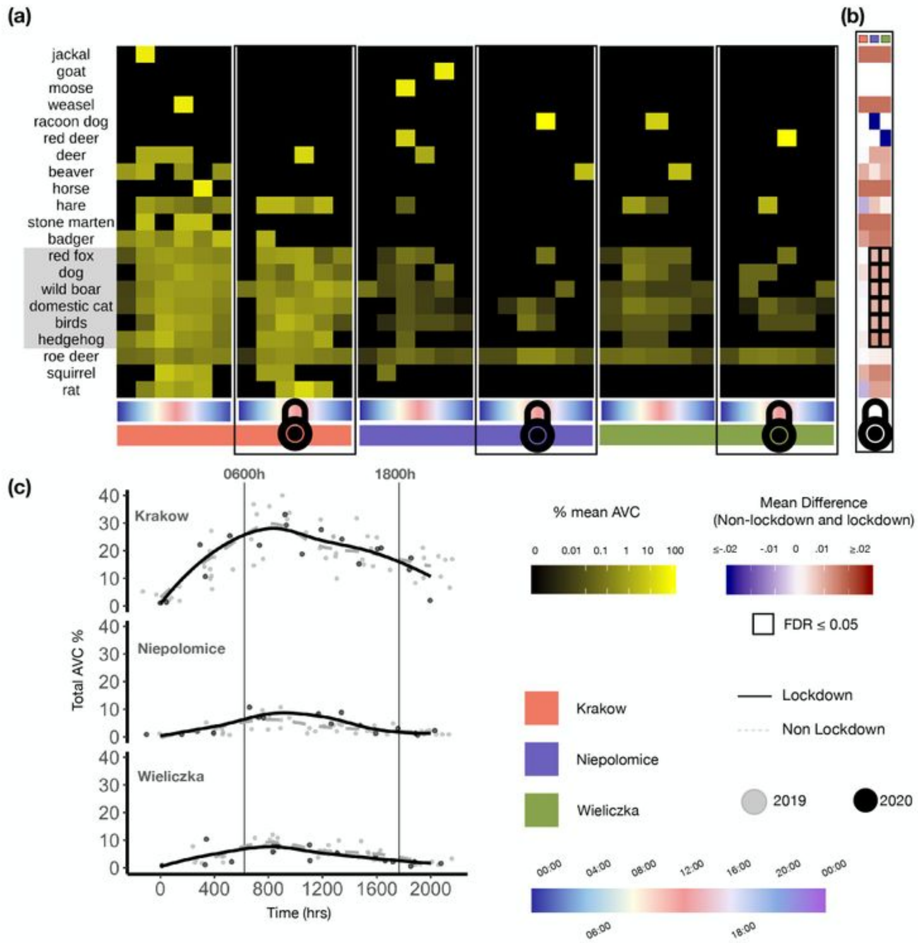

Figure 3

Working hours and its impact on AVC during the lockdown (a) The heatmap displaying the mean percentage of AVC (intensity of colour black to yellow) for the animals reported (y-axis) over a period of time period (x-axis) for specific location (bar on x-axis). The lockdown month is facetted out in the year 2020 for the corresponding hours and locations. The grey boxes on the names of animals indicate the animals that significantly differed during lockdown; (b) The pairwise comparative statistics show the mean difference between non-lockdown and lockdown period using GLM followed by multiple comparison testing (Tukey's HSD, p-adj ≤ 0.05 by BH procedure); (c) The LOESS fitted line plot represents the trend of percentage of total AVC (y-axis) across the location along the time (x-axis)

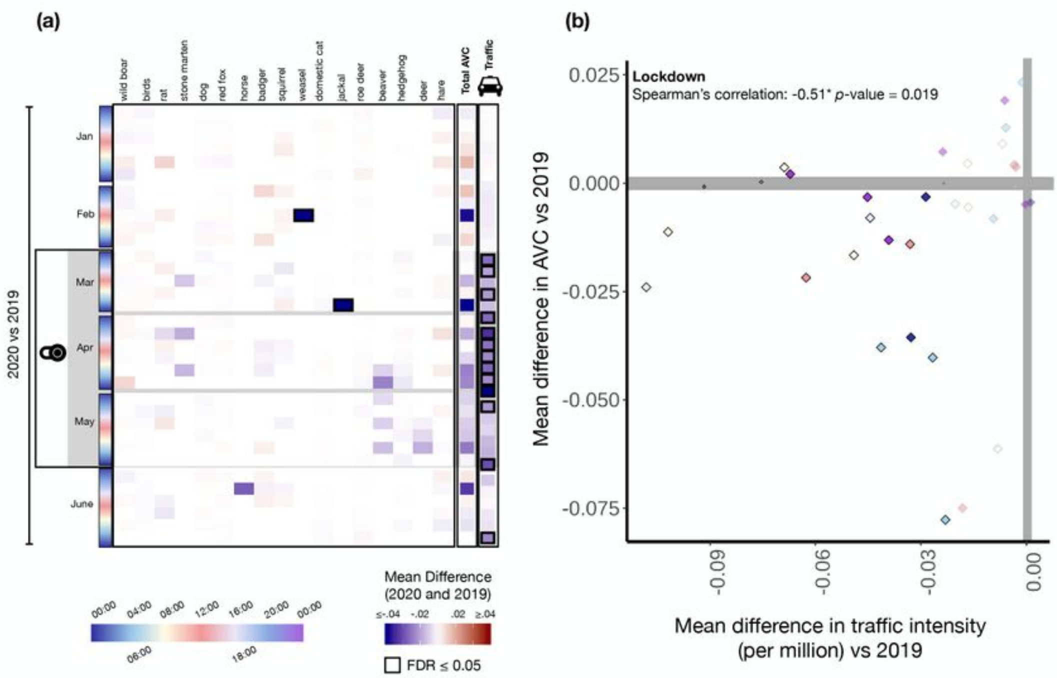

Figure 4

Traffic in Krakow during the lockdown and its impact on AVC (a) The heatmap using GLM displaying mean difference of AVC (for individual and total animals) and traffic between the 2020 and 2019 within Krakow from January to June within 24h time period. The lockdown months are facetted; (b) The scatterplot showed the mean difference between 2020 and 2019 for AVC (y-axis) and traffic volume (x-axis) by Spearman rank correlation. The x´ and y´ axes represents the |mean difference| ≤ 0.01 (marked in grey). The colour of the data points represents the time period scale. The solid datapoint represents the measure of lockdown months

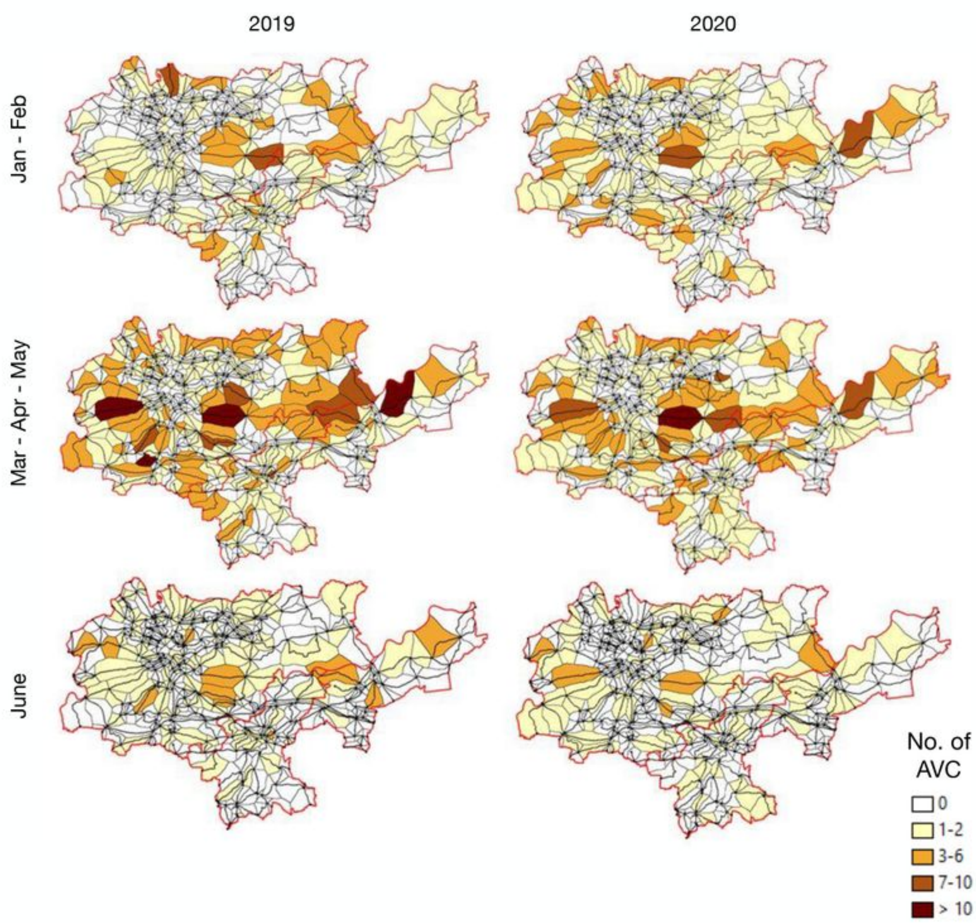

Figure 5

Spatial pattern change of AVC. Number of AVC incidents reported in regions of influence defined by the network of main streets in the studied communes of Krakow, Wieliczka and Niepolomice

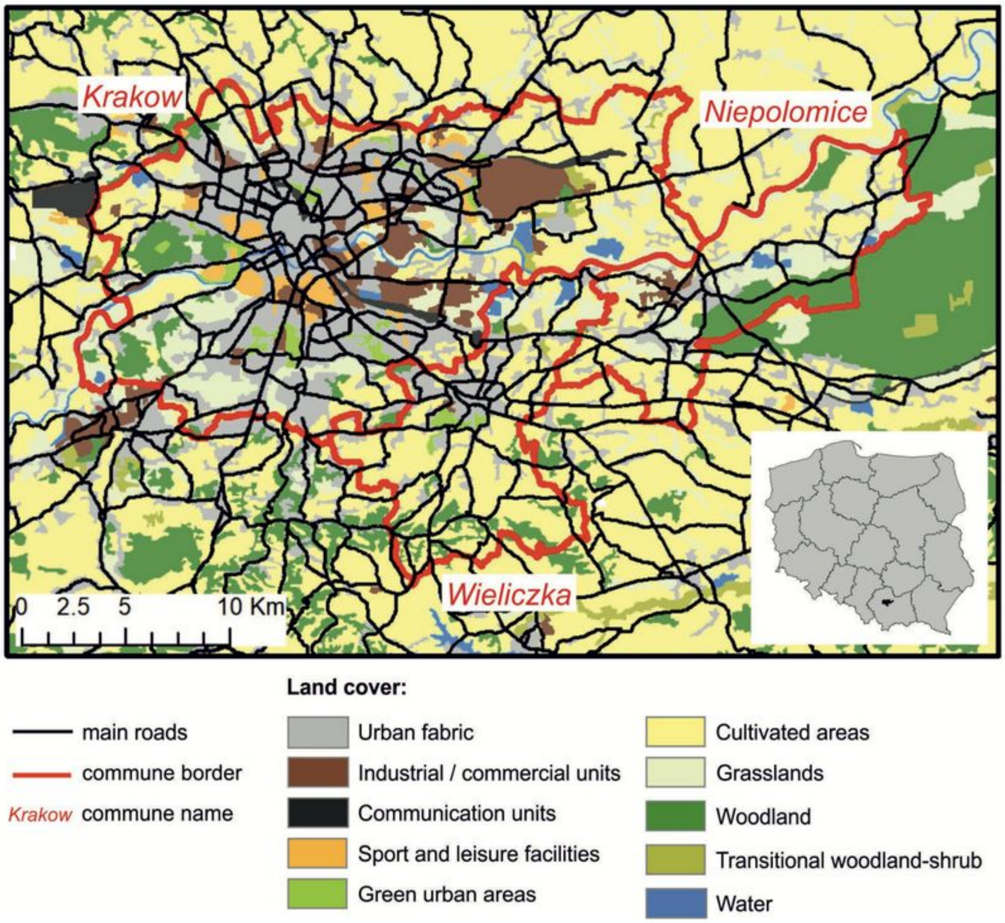

Figure 6

Land cover map of the study area. Land cover information was derived from the CORINE Land Cover 2018 (https://land.copernicus.eu/pan-european/corine-land-cover), and road layer shows all the primary, secondary and tertiary roads from the OpenStreetMap. The figure in the bottom right corner shows location of the study area in Poland

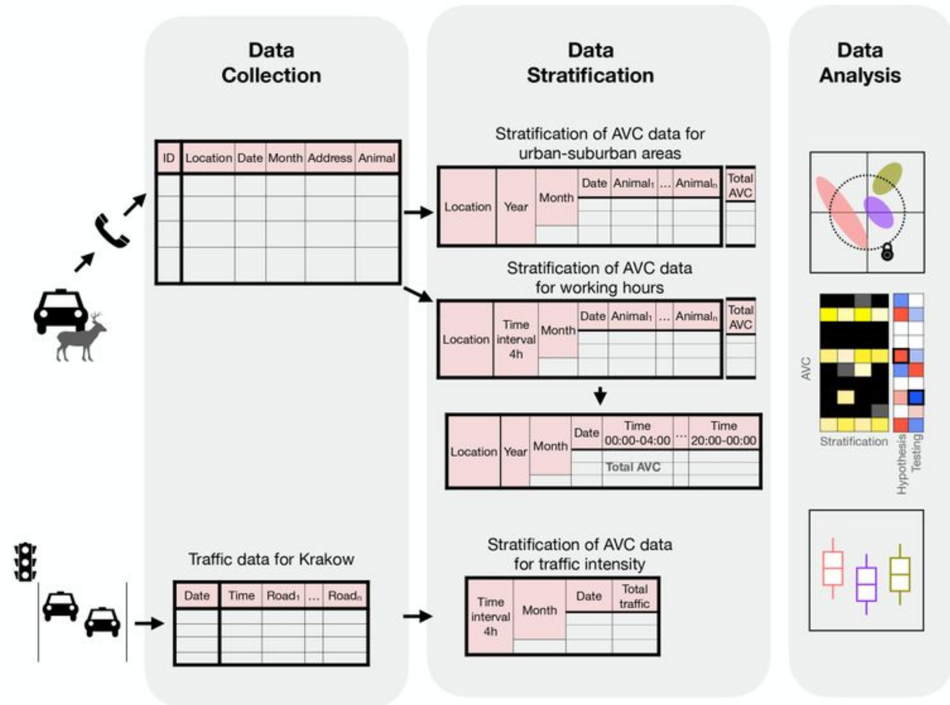

Figure 7

Workflow and data stratification. General workflow for analysing the three research questions

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryTables.xlsx
- SupplementaryFigures.docx